"Multidisciplinary Analysis & Optimization Generation 1 and Next Steps"

Presented at the NASA Fundamental Aeronautics Program 2nd Annual Meeting Atlanta, GA, October 2008

The Multidisciplinary Analysis & Optimization Working Group (MDAO WG) of the Systems Analysis Design & Optimization (SAD&O) discipline in the Fundamental Aeronautics Program's Subsonic Fixed Wing (SFW) project completed three major milestones during Fiscal Year (FY)08: "Requirements Definition" Milestone (1/31/08); "GEN 1 Integrated Multi-disciplinary Toolset" (Annual Performance Goal) (6/30/08); and "Define Architecture & Interfaces for Next Generation Open Source MDAO Framework" Milestone (9/30/08). Details of all three milestones are explained including documentation available, potential partner collaborations, and next steps in FY09.

Multidisciplinary Analysis & Optimization Generation 1 and Next Steps

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Subsonic Fixed Wing Project

Fundamental Aeronautics Program

2nd Annual Meeting

Atlanta, GA

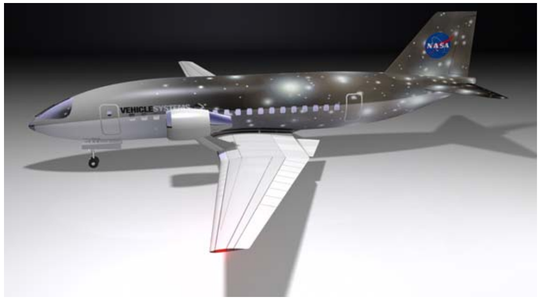
October 7-9, 2008

SFW System Level Metrics

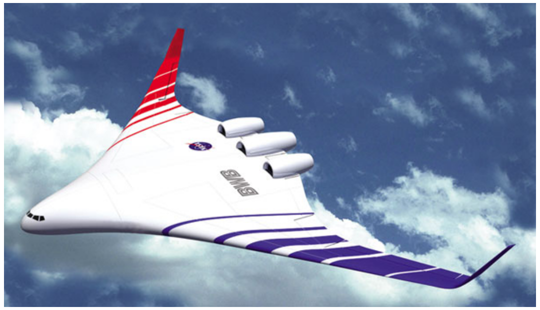
CORNERS OF THE TRADE SPACE	N+1 (2015 EIS) Generation Conventional Tube and Wing (relative to B737/CFM56)	N+2 (2020 IOC) Generation Unconventional Hybrid Wing Body (relative to B777/GE90)	N+3 (2030-2035 EIS) Generation Advanced Aircraft Concepts (relative to user defined reference)
Noise	- 32 dB (cum below Stage 4)	- 42 dB (cum below Stage 4)	55 LDN (dB) at average airport boundary
LTO NOx Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%**	-40%**	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

** An additional reduction of 10 percent may be possible through improved operational capability
* Concepts that enable optimal use of runways at mutiple airports within the metropolitan areas
EIS = Entry Into Service; IOC = Initial Operating Capability

N+1 Conventional



N+2 Hybrid Wing/Body



N+3 Generation

Topic Outline

- Background
- Organization
- Milestones
- Major Accomplishments
- Status & Plans
- Conclusion

Physics Based MDAO

- National Need: Environment & Economy
  - Unconventional configurations are essential to further reduce noise and emissions, while increasing performance.
  - PB MDAO is critical in designing & optimizing unconventional vehicles.
  - Industry needs advances in PB MDAO tools to design revolutionary vehicles in a cost-effective way.
- Benefits include
  - Enabling of unconventional design
  - Increased confidence in designs
  - Reduced technical risk, time to market, & cost
- Gaps include
  - Highly customized (and proprietary) to specific configurations and analysis processes
  - Configuration change necessitates rework
  - Lack of integrated variable fidelity capability

MDAO Working Group Organization

Fundamental Aeronautics Program Office
Director: Juan Alonso

MDAO Integrated Discipline Group
Lead: Dean Kontinos

Subsonic Fixed Wing Project

Principal Investigator: Fay Collier

Project Scientist: Richard Wahls, **Project Manager:** Ruben Del Rosario, **Tech Integrator:** Anna Mcgowan

Acoustics API: Russell Thomas
Aerodynamics API: Mike Rogers
Aeroelasticity API: Jennifer Heeg
Aerothermodynamics API: Jim Heidmann
Combustion API: Dan Bulzan
Controls & Dynamics API: Diana Acosta
Materials & Structures API: Karen Taminger
SAD&O API: Bill Haller

SAD&O TWG

MDAO Working Group

Level 3 Lead
Steve Smith

Software Development Lead
Cynthia Naiman

Level 4 Lead
Craig Nickol

Supersonic Project
API: Lori Ozoroski

GEN1 Validation Subteam
Lead: Haller

GEN2 HWB Subteam
Lead: Nickol

OpenMDAO Subteam
Lead: Naiman

Discipline, Systems, & MAO Experts
- Acoustics
- Aeroelasticity
- Combustion
- Materials & Structures
- Aerodynamics
- Aerothermodynamics
- Controls & Dynamics
- SAD&O

Computer Scientists

Support
- Software Testing
- Software Configuration Management
- Technical Writing
- System Administration

MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008

- Requirements defined applicable to all milestones

MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008

Requirements defined applicable to all milestones
GEN1 milestones

MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008
Complete GEN 2 Integrated Multi-disciplinary Toolset	6/2010
GEN 2 Validation of Integrated Tool Set w/Experimental Data	12/2010

Requirements defined applicable to all milestones

GEN1 milestones

GEN2 milestones

MDAO Milestones

Title	End Date
Define Requirements for Integrated Design/Analysis Environment	1/2008 ★
Complete GEN 1 Integrated Multi-disciplinary Toolset	6/2008 ★
Define Architecture & Interfaces for Next Generation Open Source MDAO Framework	9/2008 ★
GEN 1 Validation of Integrated Tool Set w/Experimental Data	12/2008
Complete GEN 2 Integrated Multi-disciplinary Toolset	6/2010
Complete Alpha Release of Next Generation Open Source MDAO Framework	9/2010
GEN 2 Validation of Integrated Tool Set w/Experimental Data	12/2010
Demonstrate Next Generation Open Source MDAO Framework	9/2012

Requirements defined applicable to all milestones

GEN1 milestones

GEN2 milestones

Open Source milestones

FY08 Major Accomplishments

- Met "Requirements Definition" Milestone (1/31/08)
  - Completed:
    - *Vision & Scope Document*
    - *Use Case Document*
    - *Software Requirements Specification (424 functional & 23 non-functional)*
    - *Glossary*
    - *Requirements Prioritization*
- GEN1
  - Met "GEN 1 Integrated Multi-disciplinary Toolset" (Annual Performance Goal) (6/30/08)
    - Completed Improvements to Codes & Integration Techniques: stability and control, noise, medium-fidelity aero prediction, high-lift aero prediction, and aircraft synthesis
    - Verified Improvements Using Demonstration Cases: Ultra High Bypass Engine, DC9 Drag Polar, Supersonic Business Jet/Mixed Flow Turbofan
  - Completed *GEN 1 Integrated Multi-disciplinary Toolset SFW.01.01.009 Milestone Report* (6/30/08)
  - Hosted GEN1 Review Day (7/29/08)
  - Defined validation plan (conventional configuration)
- GEN2
  - Defined validation plan (conventional & unconventional configurations)
- OpenMDAO
  - Presented paper at AIAA MAO Conference: *AIAA-2008-6069 "The Development of an Open-Source Framework for Multidisciplinary Analysis and Optimization"* by Moore, Naylor, & Gray
  - Met "Define Architecture & Interfaces for Next Generation Open Source MDAO Framework" Milestone (9/30/08)
  - Completed *Next Generation Open Source MDAO Framework Architecture Document* (9/30/08)

Decision Point: Parallel Path Approach

2008 — *Near Term Solutions* — *2010* — *Far Term Solutions* — *2012 & beyond*

GEN 1 Toolset Development

MDAO Requirements Definition

Near Term Path: Continue to use & improve currently available frameworks to meet near-term milestones (GEN2)

Far Term Path: Develop open source framework as start of long-term solution (Alpha)

Far Term Path: Next Generation Open Source MDAO Framework (OpenMDAO)

Why Open Source? *Components & Collaboration*

A framework is only as good as its components

- Open source → more users
- More users → more component developers
- More component developers → more components
- More components → more functionality for users

- We can maximize the number of available components by making it easy to package a component and publish it on the web

- Easier collaboration
  - No need to pay a price per seat to purchase the framework
  - Minimal red tape; just download it, install it, and go

- Transparency -- Source code can be viewed by users
  - Researchers can see the algorithms
  - Many eyes find many bugs

Government Interest In Open Source Distribution

- NASA *(Outreach, Tech Transfer, Contributions back to NASA)*
  - NASA's Motivation for Open Source software distribution:
    - To increase NASA software quality via community peer review
    - To accelerate software development via community contributions
    - To maximize the awareness and impact of NASA research
    - To increase dissemination of NASA software in support of NASA's education mission
  - "Developing An Open Source Option for NASA Software" by Moran, TR NAS-03-009
  - NASA Open Source Agreement (NOSA)
- DoD
  - "Open Source Software (OSS) and the U.S. Department of Defense (DoD)" by Wheeler, 2/11/08, http://www.dwheeler.com/oss-dod-webinar2008.html

Status & Plans

- GEN1
  - Prepare model to validate GEN1 (due 12/08)
- GEN2
  - Identify specific codes & integration improvements needed for HWB configuration
- OpenMDAO: OS framework does not require that components be OS
  - Pursue potential collaboration in OS MDAO community
  - Identify & define verification/validation test cases
  - Continue prototyping using python
  - Set up development environment & begin implementation
  - Follow process to classify framework as open source & publicly available
  - Follow up with industry, academia, & other government agencies
- Leverage NRA & SBIR MDAO efforts

Conclusion

- Completed 3 major milestones in FY08
- On schedule to meet future milestones
- 2-Path approach benefits near- and long-term needs
- Partnering with industry, academia, and other government agencies is essential to realize MDAO vision

Data on Requirements Development

Requirements Inspections

	Infrastructure 1	Infrastructure 2	Infrastructure 3	Infrastructure 4	Noise Tools	Geometry Tools	Mission Perf Tools	Uncertainty Tools	Emissions & Propulsion	Misc. Tools 1	Misc. Tools 2	Total
# of Reqs inspected	52	48	49	35	85	68	54	41	42	41	29	544
# of Defects Found	85	52	46	24	43	128	70	67	56	87	58	716
# of people attending inspections*	8	7	7	7	7	7	7	8	9	9	7	n/a
Hours in inspection meeting**	2.5	2.25	1.25	2	4	6	2.25	2	3	2.75	2.25	30.25
eRoom discussion forums***	2	2	2	5	6	9	6	0	1	6	2	41

Priorities for Functional Requirements

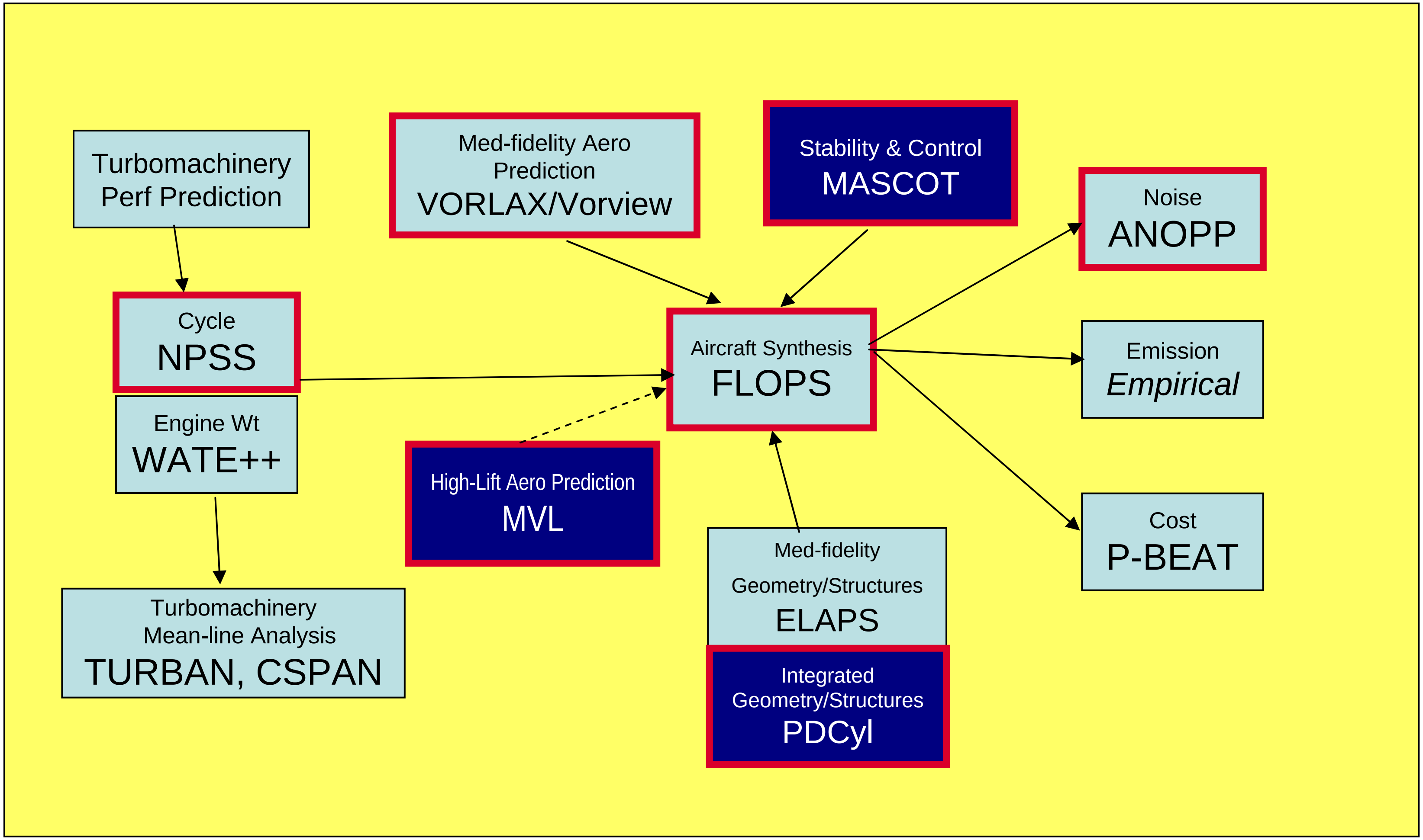
MDAO Framework Requirements

Category	Mandatory	High	Special Med.	Med	Low	Cat. Totals
Component Management	3	6	2	2		13
External Interface	1	7		7	6	21
Sim Configuration	4	6		3		13
Sim Data	1	3	1	2		7
Sim Execution	4	9	1	2		16
System Operations	2	4	3	1		10
Tool Coupling	5	4	1	3	8	21
Tool Wrapping	7	5	1	2	1	16
User Interface	13	21	7	14		55
Totals	40	65	16	36	15	172

MDAO Non-Framework Requirements

Category	Mandatory	High	Special Med.	Med	Low	Cat. Totals
Acoustics	13	24		14		51
Aerodynamics	2	12		1		15
Approximation	1	5	1	3		10
Cost	0	5		3		8
Design	5	6		3		14
Emissions	0	5		7	1	13
Geometry	12	11	9	6	3	41
Mission Perf	25	12		7		44
Optimization	0	11		1		12
Propulsion	7	7		9		23
Stability & Control	4	7	1	3		15
Structural Analysis	3	9		1		13
Take-off & Landing	6	2				8
Uncertainty	0	9		4	1	14
Totals	**78**	**114**	**2**	**56**	**2**	**252**

GEN 1 MDAO Framework Schematic



- Dark blue boxes indicate new capabilities over the GEN 0 Framework
- Red outline boxes identify tools discussed in further detail in GEN1 Milestone Report
- Solid arrows – integrated   Dashed arrows – not integrated yet

OpenMDAO Architecture Document

- Top level context diagram
- Class diagram of most important classes, followed by descriptions of each class
- Sequence diagrams covering important areas, such as component execution and component creation
- A list of interfaces for system plug-ins (IComponent, IDriver, ICaseIterator, IResourceAllocator,...)
- Important design decisions and reasoning behind them
- Deployment diagram for component publishing/downloading via egg servers
- Deployment diagram for a distributed model execution